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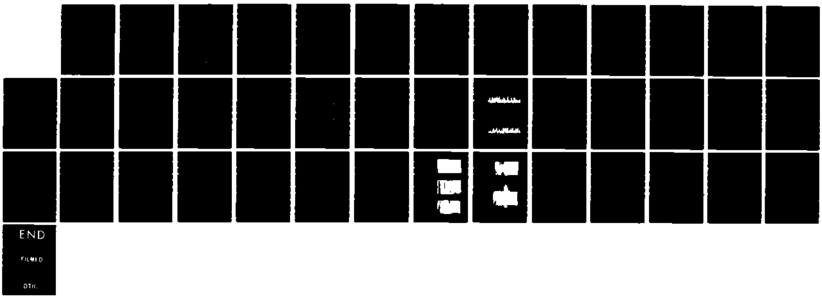

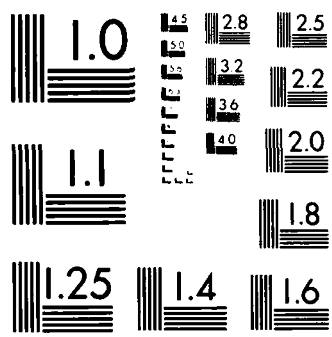

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MELBOURNE, VICTORIA

Structures Technical Memorandum 388

A COMPARISON OF FATIGUE LIVES UNDER A COMPLEX AND A MUCH SIMPLIFIED FLIGHT-BY-FLIGHT TESTING SEQUENCE

J.Y. MANN and G.W. REVILL

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J.Y. MANN, G.W. REVILL

SUMMARY

Flight-by-flight fatigue tests were carried out on specimens representing part of the front flange of the main spar of the Mirage III wing. Two loading spectra/loading sequences were used, the first being a 200-flight sequence incorporating 24 different types of flight developed by the Eidgenossisches Flugzeugwerk in Switzerland and the second a much simplified 100-flight sequence incorporating only 4 different types of flight developed by Avions Marcel Dassault in France.

The fatigue tests showed that there were no significant differences in the lives to failure between specimens tested under the two sequences, and it was therefore concluded that the use of the simplified stress spectrum/sequence would not have invalidated the findings of a previous investigation to develop life-enhancement procedures for the Mirage wing main spar.

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1. INTRODUCTION

Investigations have been carried out in Switzerland, Australia and France to determine the fatigue behaviour of the Mirage III wing and to develop procedures for increasing the life of the main spar (Refs 1-3).

The loading sequence used during the fatigue testing of the complete structure in Switzerland (at the Eidgenössisches Flugzeugwerk (F+W), Emmen) was a 200 flight flight-by-flight sequence made up of 24 distinct flights. However, most of the fatigue tests at the Aeronautical Research Laboratories (ARL) on specimens representing sections of the spar flange - including those used to develop the rear flange refurbishment techniques (Ref. 3) - were carried out using a 100 flight flight-by-flight sequence of only four different types of flight which Avions Marcel Dassault (AMD) had derived from a much simplified version of the Swiss load spectrum.

In order to demonstrate whether the findings of the various spar life-enhancement investigations might have been invalidated by the use of the simplified spectrum/sequence, a program of comparative fatigue tests was undertaken using the two spectra/sequences. The results of these tests are covered by this report.

2. FATIGUE LOADING SPECTRA

The test load spectrum adopted for the full-scale Mirage III fatigue test at the F+W was derived from fatigue meter records and strain measurements on aircraft in the Swiss Mirage fleet (Ref. 4). Various missions were defined and identified by 24 "typical" flights which were then combined to provide the required load spectrum in a test sequence containing 200 flights. The cumulative frequency spectrum of 'g' exceedances is shown in Fig. 1 and the order of occurrence of the 24 distinct flights in the 200-flight sequence is given in Table 1 (Ref. 5). It should be noted that the maximum load of the sequence (+7.5g) occurs twice in each sequence of 200 flights - in flights 48 and 150. Each typical flight consisted of three or four segments (representing, for example, take-off, combat, landing), the actual load sequence in each being appropriate to the particular segment.

During the development of the Mirage III aircraft AMD derived a much simplified version of the Swiss test spectrum which consisted of only four different types of flight arranged into the 100-flight sequence shown in Fig. 2. Each 100-flight sequence

included only one occurrence of the maximum load of +7.5g - during flight 42, and adopted a lo-hi-lo sequence of loads within each "flight". The cumulative frequency spectrum of loads for the French sequence is also shown in Fig. 1. Except at low loads, both the Swiss and French load spectra are very similar.

3. TEST SPECIMENS AND MATERIAL

Figure 3 illustrates the type of low-shear-load-transfer bolted joint fatigue specimen used in this investigation. It was designed to represent the lower front flange of the main spar of the Mirage III at the position (hole no. 12) at which the major failure had occurred in the first series of full-scale fatigue tests on the structure carried out at the F+W. Although identical to the specimens used in the testing program reported in Ref. 2, only two of the variants of hole treatments and fasteners were used in the current tests namely:

(i) Type C, where the bolt holes were cold-expanded by the Boeing Split-Sleeve process (Ref. 6) by nominally 3% and 0.25 inch clearance-fit bolts used as the fasteners, and

(ii) Type D, where 8.15 mm outside diameter interference-fit bushes of grade 304 austenitic stainless steel were inserted in the holes and 5 mm clearance-fit fasteners used. The bush interference was 0.25 to 0.35%.

Full details of the cold-expansion and interference-fit bushing treatments which were adopted are given in Appendix 3 of Ref. 2.

The fatigue specimens were made from aluminium alloy B.S. L168 supplied in the form of 63.5 mm x 31.75 mm extruded bars. Specification values for the tensile properties and chemical composition together with those derived from ARL tests on the particular batch of material (laboratory code GR) are given in Table 2. Table 2 also includes the results of tests on compact tension fracture toughness specimens taken from offcuts of the extrusions. The notch in these specimens was machined in the long transverse direction.

4. FATIGUE TESTS

The fatigue testing program included 22 of the cold-expanded hole specimens (Type C) and eight specimens incorporating interference-fit bushes (Type D). About half of each type were tested under the French and Swiss sequences respectively.

All fatigue tests were carried out in a Tinius-Olsen servo-controlled electro-hydraulic fatigue machine. The French sequence was achieved using an EMR Model 1641 programmable function generator controlled by a punched tape and operating in sine wave mode; while the Swiss sequence was achieved through a DEC PDP 11/20 computer, using a control tape with a strain sequence corresponding to that at hole no. 12 in the Swiss full-scale test. This sequence was deduced from that at a strain gauge (position 1.4T) located near hole no. 12. The computer control provided a quasi-sinusoidal cyclic loading.

Fatigue loads were calculated on the basis that +7.5g corresponded to a gross-section-area stress (not including the skin plates) of 235 MPa (see Appendix), and that for the French sequence there was a single linear stress/g relationship, i.e. the 1g gross-area stress was 31.3 MPa (Ref. 2). The French cumulative frequency stress spectrum for +7.5g = 235 MPa is shown in Fig. 4, and the stress values for individual 'g' values are given in Table 3. Similarly, for the Swiss sequence, the +7.5g load level corresponded to 235 MPa, and stress and 'g' were linearly related. However, because of different loading cases within individual flights in the Swiss sequence (associated, for example, with fuel usage, elevon operation, the use of air brakes), there is not a unique stress/g relationship for every value of 'g'. Consequently, there are some differences between the Swiss cumulative frequency stress spectrum (Fig. 4) and load spectrum (Fig. 1) relative to the respective French spectra and, furthermore, the Swiss stress spectrum incorporates a much greater number of low-amplitude loads than does the French. Some tests were also carried out in which all stresses were scaled upwards by a factor of 1.25, i.e. at +7.5g the corresponding stress was 294 MPa. A trace of the stress sequence under the Swiss spectrum around flights 48 and 150 is shown in Fig. 5.

For tests involving the French sequence, cycles of +6.5g to -1.5g and +7.5g to -2.5g (a total of 39 cycles in 100 flights) were applied at a cyclic frequency of 1 Hz, whereas the remaining 1950 cycles per 100 flights were at 3 Hz. One 100-flight sequence took about 12 minutes to complete. The Swiss 200-flight test sequence (which consisted of about 2 x 10^4 cycles) was applied at an average frequency of 9.3 Hz, and took about 36 minutes to complete.

Fatigue test results for all specimens are given in Table 4. The "failure" bolt hole identification is shown on Fig. 3.

5. FATIGUE FRACTURES

The fracture surfaces of all specimens broken in this investigation are shown diagramatically in Fig. 6, and photographs of representative fractures are illustrated in Fig. 7. These show that

holes nos 2 and 4 predominated as the holes from which the major fatigue crack development occurred, the only exceptions being two of the interference-fit bush specimens where the major crack initiation was close to hole no. 1. However, the actual fracture path in all but one of the 30 specimens tested passed through an adjacent bolt hole and in about half the cases provided evidence of fatigue cracking at these holes.

In the cold-expanded-hole specimens the fatigue fracture developed from multiple crack initiation along the bores of the holes whereas, for the interference-fit bush specimens, initiation by fretting at one or both faces of the specimen was more usual. Of the 22 cold-expanded hole specimens, the fatigue crack development in five approximated a through-the-thickness crack situation. In thirteen of the remainder the major cracking occurred at the end of the hole corresponding to the entrance point of the expansion mandrel, while for the other four specimens, it was at the exit end.

6. DISCUSSION

Table 5 summarises the results of the fatigue tests and provides a comparison of the average lives of the three groups of tests covered by the investigation.

The previous investigation (Ref. 2), which included tests under the French sequence only, demonstrated the superiority of the interference-fit bush system compared with hole cold-expansion for fatigue life enhancement. Those findings are supported by the present tests under the Swiss sequence.

Although the numerical values of the mean lives given in Table 5 for groups of specimens tested under the French spectrum are greater than those under the Swiss spectrum, the differences for individual groups are statistically significant* only for the cold-expanded hole specimens tested with +7.5g = 294 MPa. However, a comparison of the French and Swiss sequences based on a two-way analysis of variance and a pooling of the respective results for the two sequences indicated no significant differences in their average lives.

This result is not surprising as tests (Ref. 8) on larger bolted joints under the French sequence indicated that the estimated damage contribution from the lowest load range in the sequence amounted to only about 6% of the total damage. As in the current investigation, the minimum load range was 20% of the maximum load range of the sequence. Other multi-load-level fatigue tests on

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* At a level of significance of 5%.

multiple-bolted joints of sheet/plate aluminium alloys have also shown that the omission of stress ranges up to and above the fatigue limit (corresponding to 25% of the maximum stress range) have no significant effect on fatigue lives (Ref. 9); and that load ranges of 25% of the maximum range contributed an estimated 10% of the total damage (Ref. 10). Similarly, Broek and Smith (Ref. 11) have shown that the omission of load ranges of up to about 25% of the maximum load range of the spectrum have no significant effects on the crack growth behaviour and fatigue lives of centre-notched panels of 7075-T3 aluminium alloy. These findings support the proposal (Ref. 12) that load amplitudes of up to 20% of the maximum load amplitude in a multi-load-level sequence might be omitted without significantly affecting fatigue lives.

Thus, on the basis of this investigation, there is no evidence to suggest that the conclusions arrived at from the Mirage III spar life-enhancement investigation (Ref. 3) would be invalidated because of the use of a relatively simple flight-by-flight loading sequence for that testing program.

7. CONCLUSIONS

Flight-by-flight fatigue tests carried out on specimens representing part of the front flange of the main spar of Mirage III wings have indicated:

(i) that there are no significant differences in the lives to failure between specimens tested under a complex flight-by-flight sequence incorporating 24 types of flight and a much simplified flight-by-flight sequence of only four types of flight; and

(ii) that the findings of a previous investigation to develop life-enhancement procedures for the Mirage wing main spar would not be invalidated by the use of the simplified spectrum/sequence.

ACKNOWLEDGEMENTS

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APPENDIX

Derivation of test stresses

The stress at 7.5 g was derived from strains measured at gauge 1.4T during the 1979 strain survey of the left-hand Swiss Mirage test wing. This gauge was located at the inner surface of the lower front flange of the main spar between bolt hole no. 14 and the spar web, and a multiplying factor of 1.2 was used to estimate the strain at the Swiss failure location (hole no. 12). Two different methods were used to estimate the strain at 7.5 g, and the value of 235 MPa adopted for this investigation was an average of the two. The first was determined directly from the actual numerical value of strain at 5 g using the ratio 7.5 (g)/5 (g) and resulted in a strain of 3240 microstrain (stress 237 MPa). The second method was based on the average microstrain per g from the 1 g to 5 g increment (Ref. 7) and resulted in a strain of 3201 microstrain (stress 234 MPa).

TABLE 1 - SEQUENCE OF THE 24 "TYPICAL" FLIGHTS (TF) IN F+W 200-FLIGHT TEST LOADING SEQUENCE (REF. 5)

Flights

1 to 40	41 to 80	81 to 120	121 to 160	161 to 200
1 TF14	41 TF14	81 TF14	121 TF9	161 TF22
2 TF10	42 TF12	82 TF10	122 TF5	162 TF4
3 TF6	43 TF21	83 TF15	123 TF5	163 TF12
4 TF11	44 TF6	84 TF23	124 TF16	164 TF11
5 TF15	45 TF17	85 TF24	125 TF13	165 TF3
6 TF16	46 TF13	86 TF21	126 TF17	166 TF14
7 TF17	47 TF10	87 TF12	127 TF21	167 TF11
8 TF21	[48 TF2]	88 TF17	128 TF22	168 TF9
9 TF23	49 TF11	89 TF19	129 TF15	169 TF11
10 TF13	50 TF21	90 TF16	130 TF17	170 TF1
11 TF11	51 TF23	91 TF6	131 TF21	171 TF14
12 TF22	52 TF13	92 TF11	132 TF12	172 TF4
13 TF24	53 TF23	93 TF13	133 TF24	173 TF21
14 TF5	54 TF15	94 TF11	134 TF14	174 TF10
15 TF12	55 TF3	95 TF20	135 TF13	175 TF13
16 TF18	56 TF19	96 TF14	136 TF24	176 TF15
17 TF14	57 TF14	97 TF7	137 TF7	177 TF21
18 TF5	58 TF7	98 TF23	138 TF23	178 TF17
19 TF23	59 TF15	99 TF4	139 TF16	179 TF23
20 TF13	60 TF12	100 TF7	140 TF22	180 TF15
21 TF3	61 TF24	101 TF5	141 TF14	181 TF6
22 TF8	62 TF23	102 TF20	142 TF10	182 TF24
23 TF21	63 TF16	103 TF11	143 TF21	183 TF11
24 TF17	64 TF21	104 TF17	144 TF4	184 TF17
25 TF11	65 TF22	105 TF18	145 TF15	185 TF24
26 TF13	66 TF19	106 TF5	146 TF5	186 TF4
27 TF15	67 TF13	107 TF10	147 TF15	187 TF21
28 TF24	68 TF22	108 TF13	148 TF24	188 TF12
29 TF21	69 TF21	109 TF4	149 TF12	189 TF20
30 TF11	70 TF8	110 TF12	[150 TF2]	190 TF10
31 TF23	71 TF24	111 TF22	151 TF11	191 TF16
32 TF22	72 TF17	112 TF13	152 TF23	192 TF5
33 TF7	73 TF10	113 TF23	153 TF8	193 TF14
34 TF11	74 TF9	114 TF11	154 TF11	194 TR23
35 TF22	75 TF15	115 TF19	155 TF23	195 TF13
36 TF6	76 TF13	116 TF10	156 TF13	196 TF23
37 TF10	77 TF16	117 TF15	157 TF9	197 TF17
38 TF14	78 TF12	118 TF18	158 TF22	198 TF15
39 TF16	79 TF14	119 TF9	159 TF17	199 TF14
40 TF8	80 TF21	120 TF11	160 TF8	200 TF16

The flights containing normal accelerations of 6.5 g and greater are underlined and the maximum values applied in such flights are listed below.

TF1	TF2	TF3	TF4	TF5
6.5 g	7.5 g	6.5 g	7.0 g	6.5 g

TABLE 2

PROPERTIES OF TEST MATERIAL

(a) Chemical composition (%)

Element	British Standard L168: 1978	Test material GR
Cu	3.9-5.0	4.29
Mg	0.2-0.8	0.43
Mn	0.4-1.2	0.76
Fe	0.5 max	0.23
Si	0.5-0.9	0.74
Ti	0.15 max	not analyzed
Cr	0.10 max	0.01
Zn	0.25 max	<0.20

(b) Static tensile

Property	British Standard L168:1978	Test material GR
0.1% proof stress (MPa)	-	466 (sd 10)
0.2% proof stress (MPa)	440	474 (sd 12)
Ultimate tensile stress (MPa)	490	524 (sd 12)
Elongation (%)	7	11 (sd 2)
0.1% PS/Ult	-	0.89

sd = standard deviation

(c) Fracture toughness (K_{Ic}) of GR material

Specimen thickness (mm)	$MPa.m^{1/2}$	$ksi.in^{1/2}$
25	34.5*	31.5*
19	32.0+	29.2+

* Average of two specimens from the one bar.

+ Average of five specimens from different bars.

Specimen no.
GR2D

Flights:
26,781

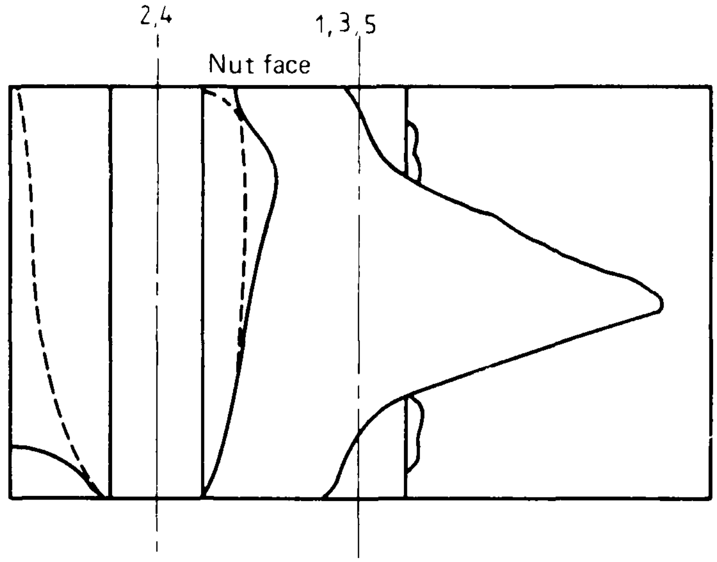
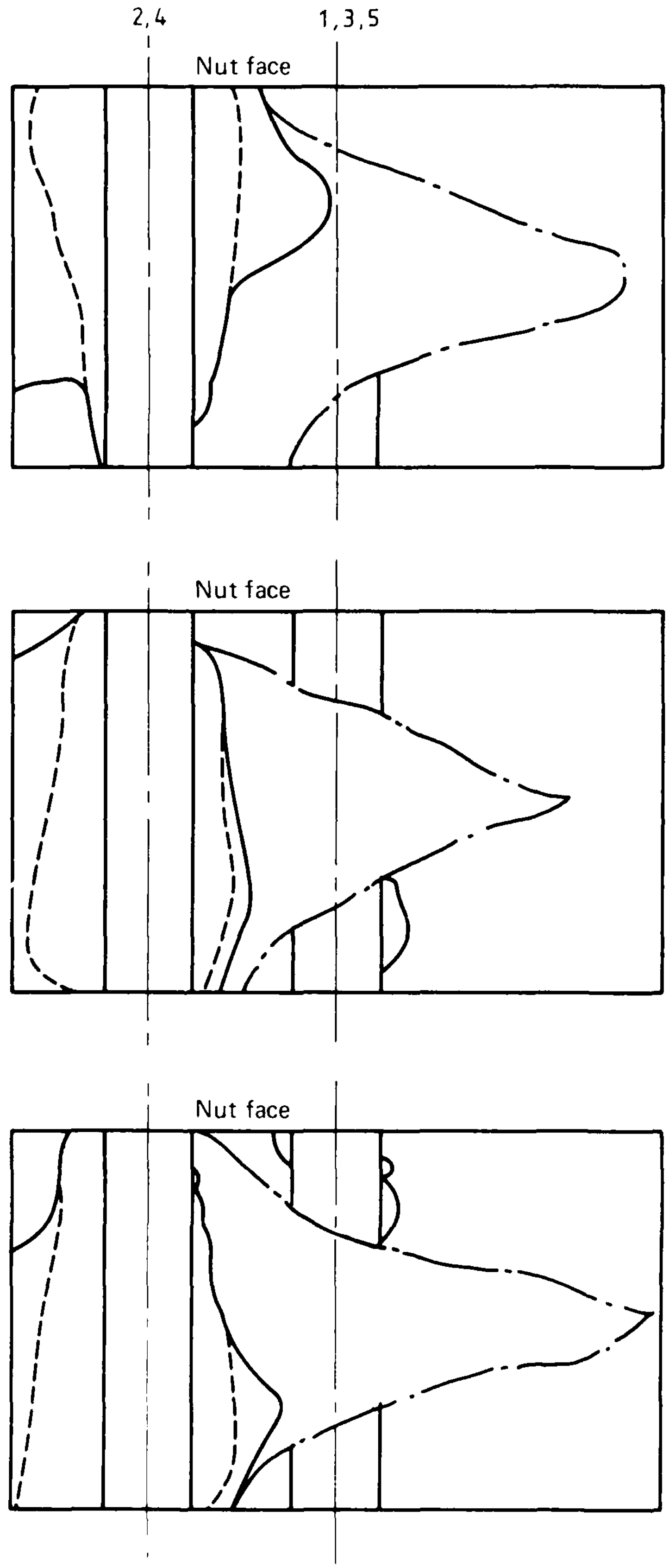


FIG. 6(a) FRACTURE SURFACES: SPECIMEN TYPE (C)
COLD - EXPANDED HOLES, FRENCH SEQUENCE,
+7.5g 235 MPa



Specimen no.
GR23D

Flights:
24,413

Specimen no.
GR9D

Flights:
25,813

Specimen no.
GR11B

Flights:
25,842

FIG. 6(a) FRACTURE SURFACES: SPECIMEN TYPE (C)
COLD EXPANDED HOLES, FRENCH SEQUENCE,
+7.5g 235 MPa

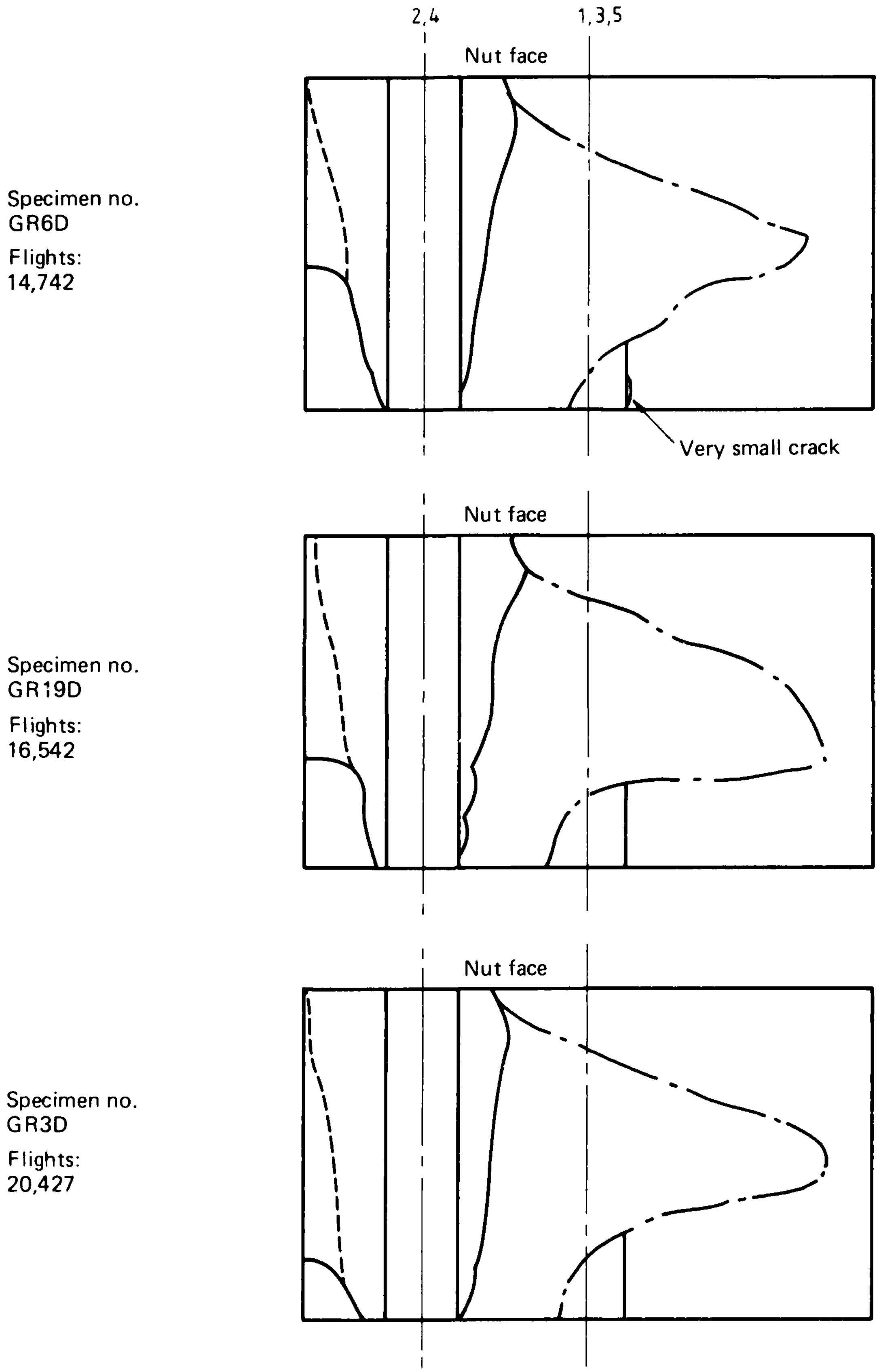


FIG. 6(a) FRACTURE SURFACES: SPECIMEN TYPE (C)
COLD – EXPANDED HOLES, FRENCH SEQUENCE,
+7.5g 235 MPa

Specimen no.
GR8B

Flights:
3,136

Specimen no.
GR12B

Flights:
3,223

(see Fig. 7(a))

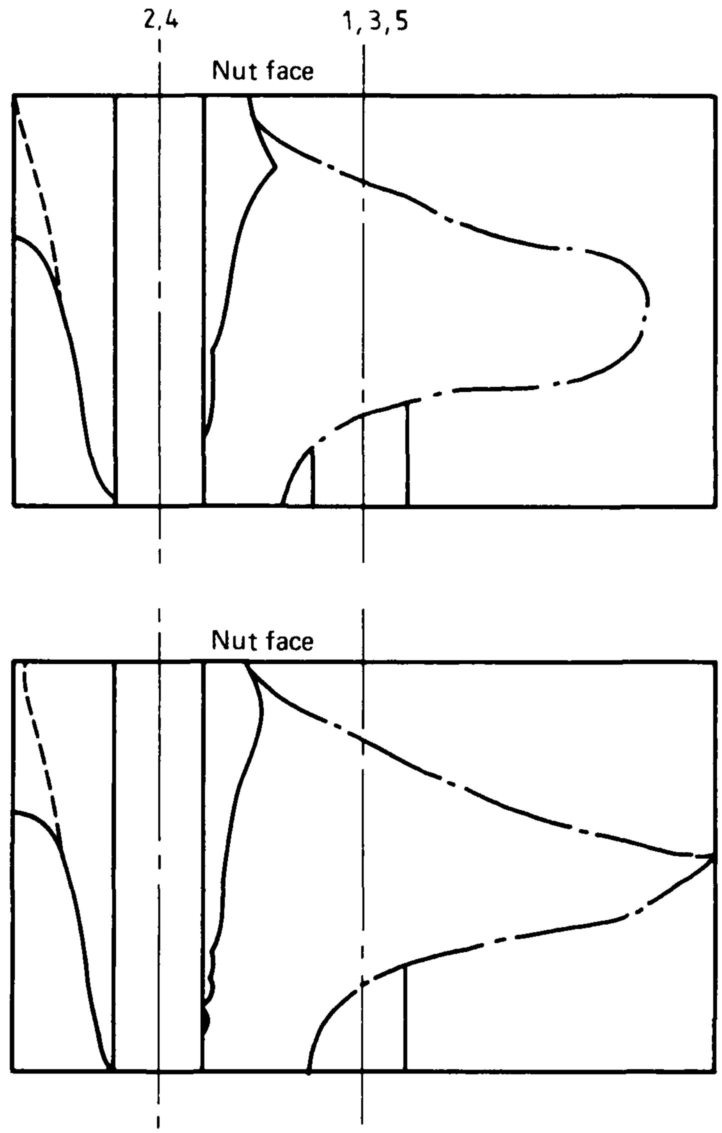


FIG. 6(a) FRACTURE SURFACES: SPECIMEN TYPE (C)
COLD – EXPANDED HOLES, FRENCH SEQUENCE,
+7.5g ≑ 294 MPa

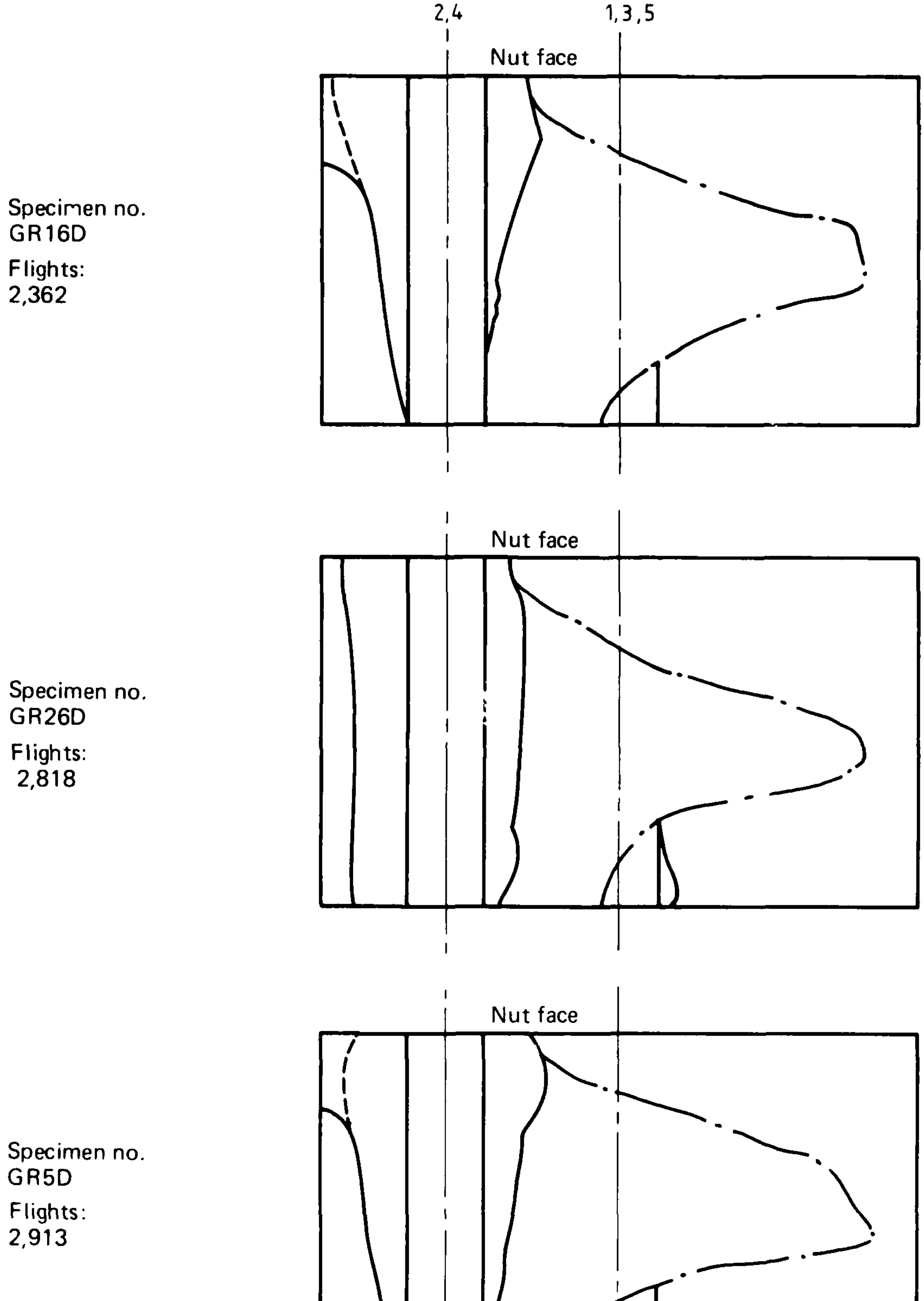
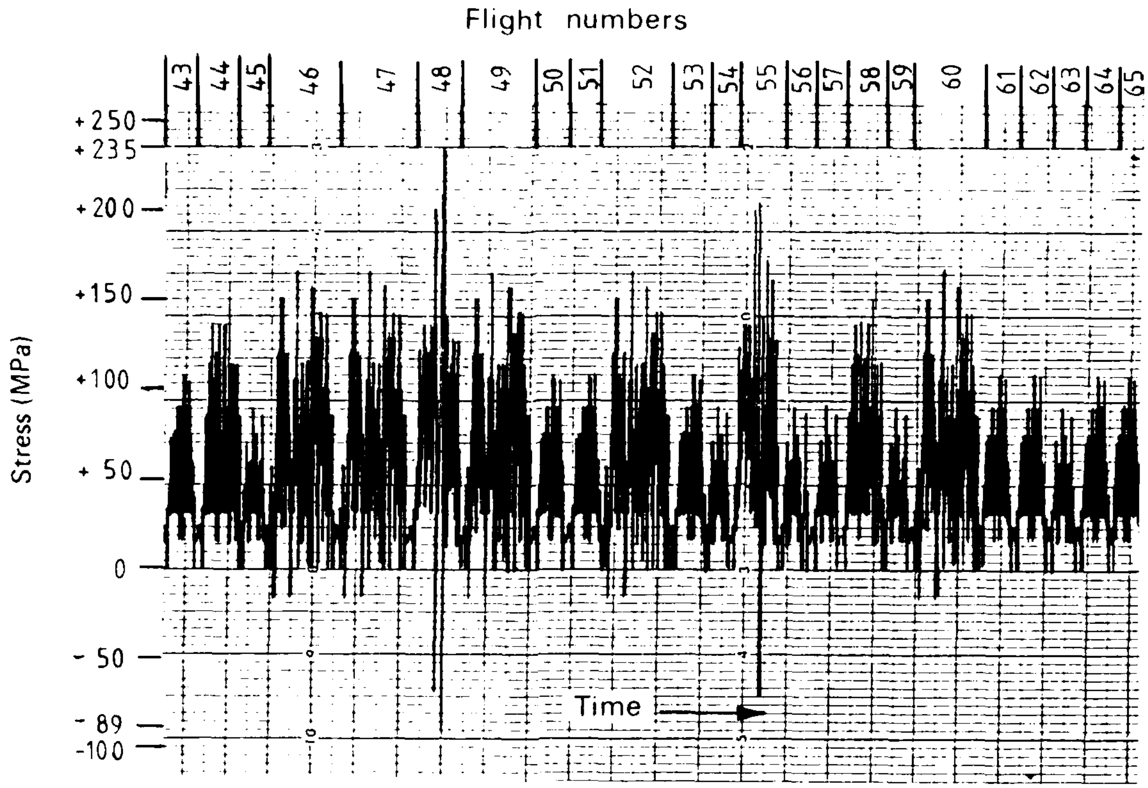


FIG. 6(a) FRACTURE SURFACES: SPECIMEN TYPE (C)
COLD - EXPANDED HOLES, FRENCH SEQUENCE,
+7.5g - 294 MPa

(The full lines indicate the approximate extent of fatigue cracking before final failure, while the small dashed lines represent the approximate boundaries of the 'flat' area of the major crack before the development of shear lips at an advanced stage of the crack propagation. The dot-dash lines represent the approximate boundaries of the shear lips at final fracture.)



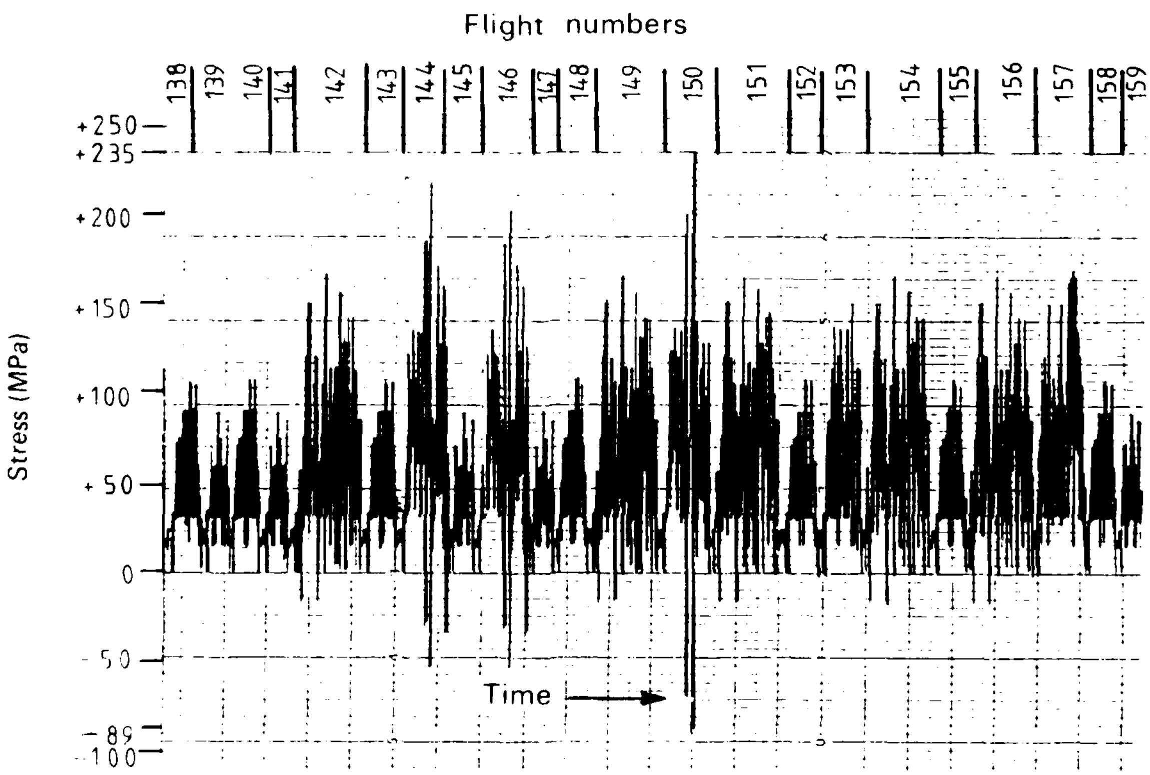


FIG. 5 STRESS SEQUENCE UNDER SWISS SPECTRUM ADJACENT TO FLIGHTS WITH +7.5g LOADS. (+7.5g 235 MPa)

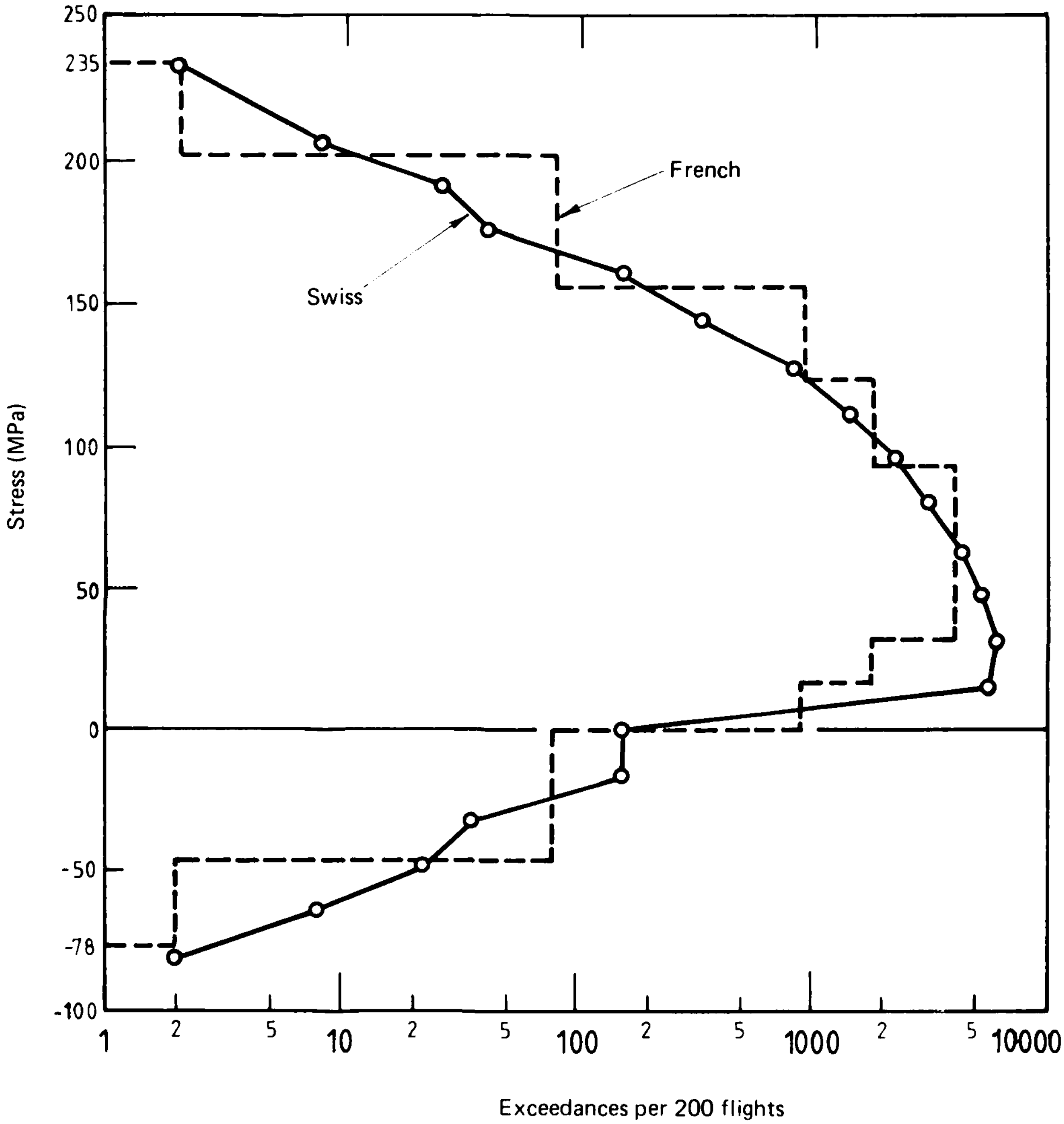


FIG. 4 STRESS SPECTRA FOR SWISS AND FRENCH SEQUENCES
(7.5g 235 MPa)

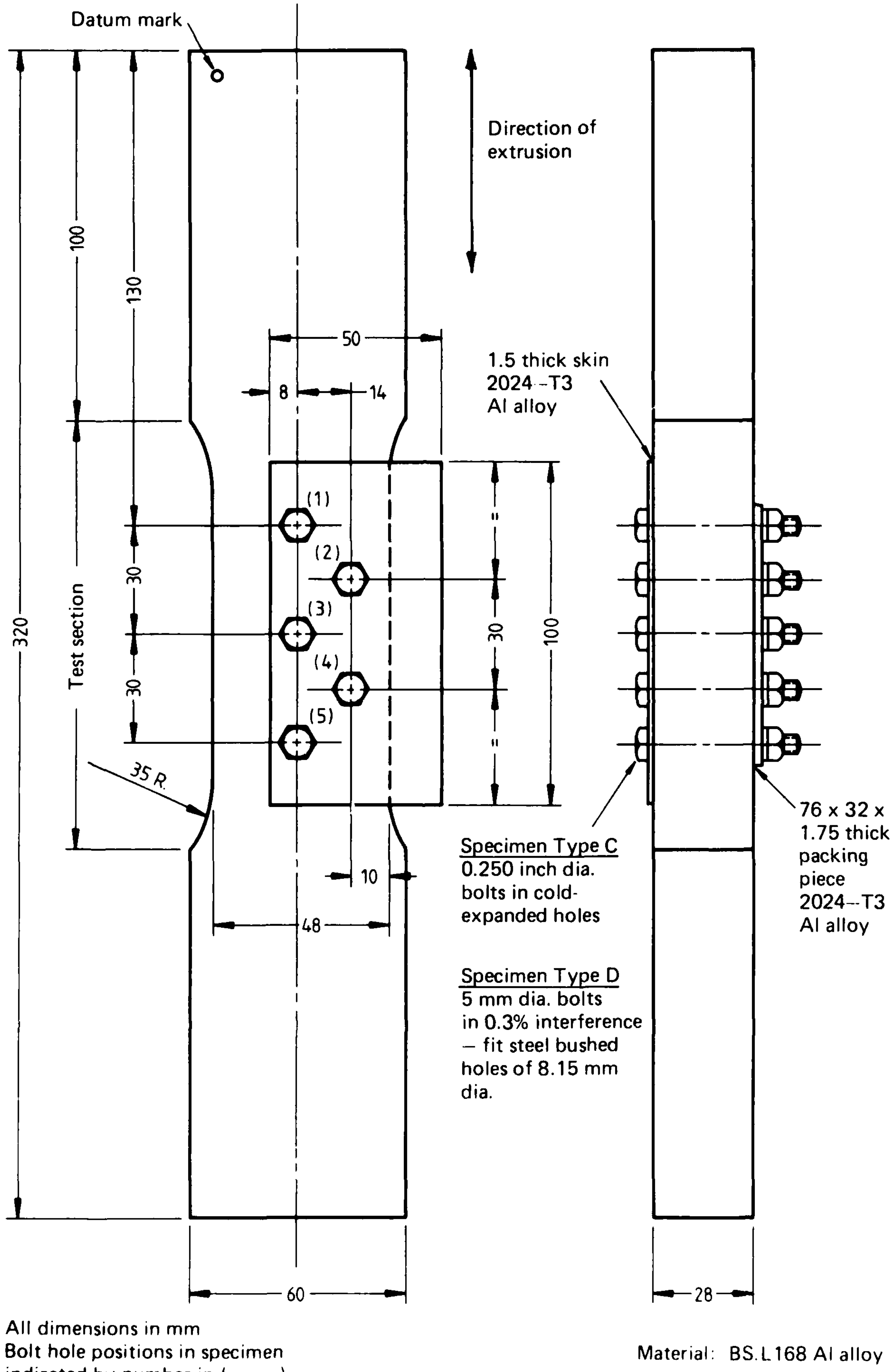


FIG. 3 MIRAGE SPAR LOWER FRONT FLANGE FATIGUE SPECIMEN

100 FLIGHTS (1989 CYCLES) REPRESENT 66.6 HOURS OF FLYING

FLIGHT A' →	10 CYCLES +3g/+1g	5 CYCLES +4g/+0.5g	2 CYCLES +5g/0g	1 CYCLE +6.5g/-1.5g	1 CYCLE +7.5g/-2.5g	1 CYCLE +6.5g/-1.5g	2 CYCLES +5g/0g	4 CYCLES +4g/+0.5g	10 CYCLES +3g/+1g
FLIGHT A →	10 CYCLES +3g/+1g	2 CYCLES +4g/+0.5g	2 CYCLES +5g/0g	2 CYCLES +6.5g/-1.5g	2 CYCLES +5g/0g	2 CYCLES +4g/+0.5g	5 CYCLES +3g/+1g		
FLIGHT B →	5 CYCLES +3g/+1g	5 CYCLES +4g/+0.5g	9 CYCLES +5g/0g	4 CYCLES +4g/+0.5g	5 CYCLES +3g/+1g				
FLIGHT C →	5 CYCLES +3g/+1g	1 CYCLE +4g/+0.5g	5 CYCLES +3g/+1g						

CYCLES OF +6.5g/-1.5g AND +7.5g/-2.5g AT 1 Hz;
REMAINDER OF CYCLES AT 3 Hz

SEQUENCE OF FLIGHTS IN 100 FLIGHTS: 1 FLIGHT A', 18 FLIGHTS A, 36 FLIGHTS B AND 45 FLIGHTS C

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
B	C	C	B	C	C	C	A	C	C	B	B	A	C	C	C	B	A	C	B	B	B	A	C	C
51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
C	B	C	C	B	C	B	B	C	C	C	A	B	A	C	C	C	B	A	B	B	B	C	B	C

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
C	A	A	C	C	B	B	B	C	B	A	B	C	C	B	A	A'	B	C	C	A	A	B	B	C
76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
C	A	B	C	B	A	B	C	C	B	A	A	B	C	C	B	C	C	B	B	C	B	C	A	C

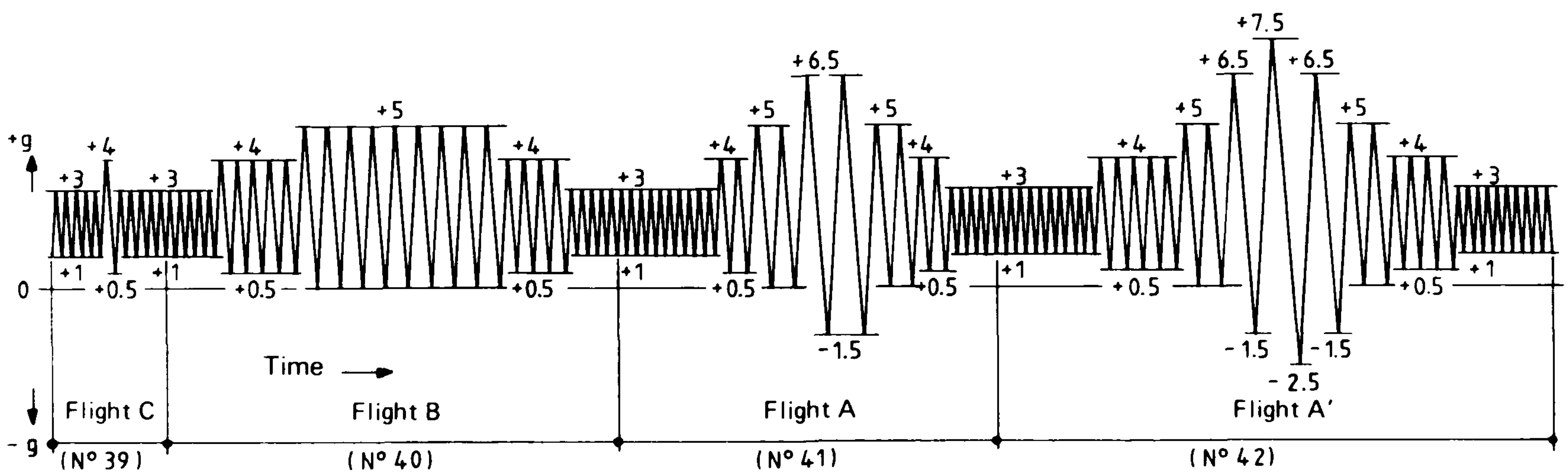


FIG. 2 FRENCH 100 FLIGHT MIRAGE III FLIGHT-BY-FLIGHT SEQUENCE

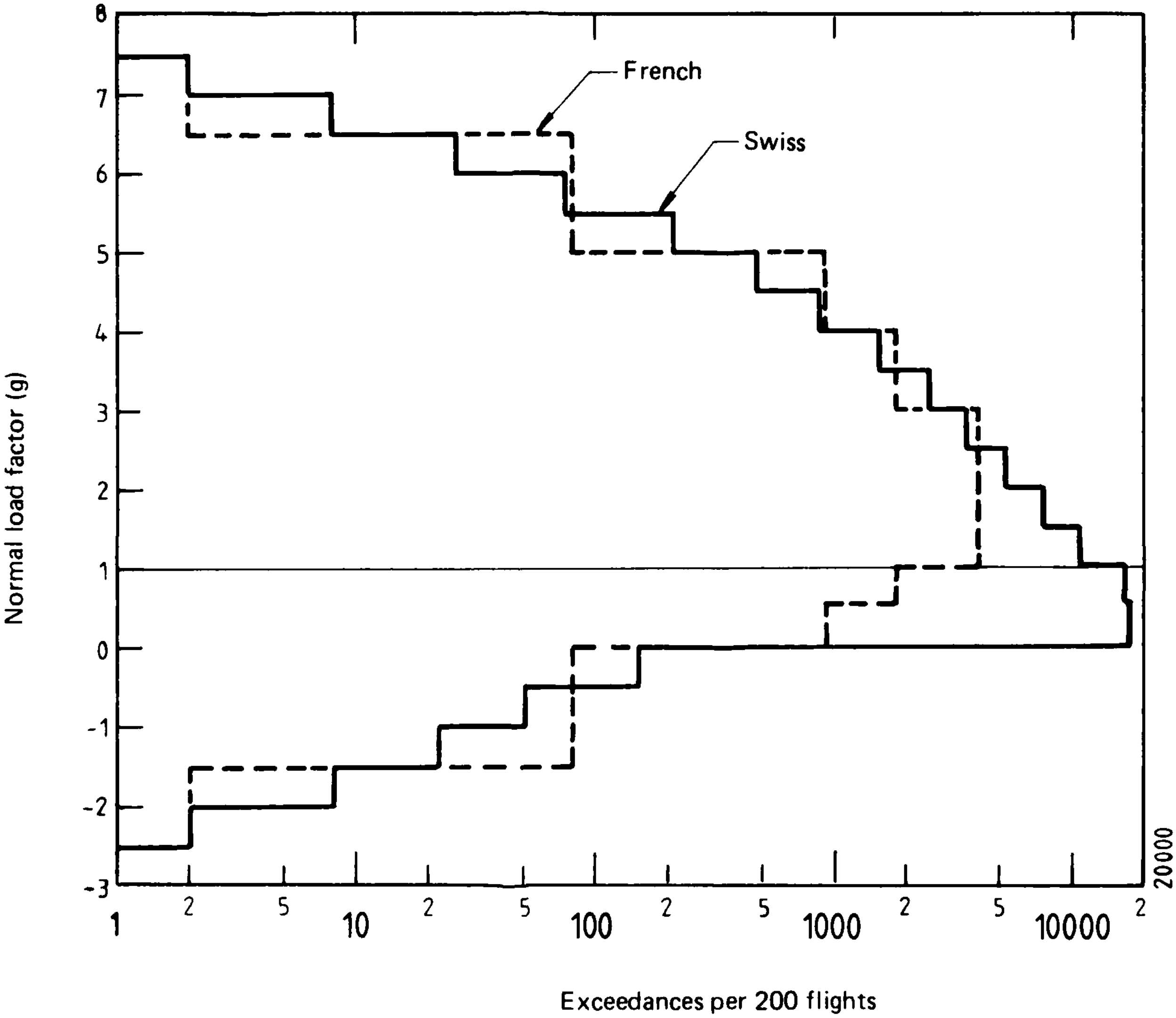


FIG. 1 LOAD SPECTRA FOR SWISS AND FRENCH TEST SEQUENCES

TABLE 5 - SUMMARY OF FATIGUE TEST RESULTS

Specimen type	7.5g stress (MPa)	Spectrum	Log. average life (flights)	Ratio French/Swiss
Cold-expanded holes	294	French	2874	1.28
		Swiss	2247	
	235	French	21570	1.21
		Swiss	17775	
Interference-fit bushed	235	French	38610	1.06
		Swiss	36354	

TABLE 4(b) - TYPE 304 STAINLESS STEEL INTERFERENCE-FIT BUSHED HOLES

Spectrum	Specimen no. GR	Gross area stress (MPa) at + 7.5 g	Life (flights)	Failure hole no.	Failing Load (kN)
French	17E	235	27013	2	271
	20E	"	30227	2	274
	23E	"	41242	1	292
	12E	"	41542	1	282
	25E	"	61342	2	287
		Log. average = 38610; s.d. of log. life = 0.139			
Swiss	21E	235	34508	2	269
	22E	"	38298	2	267
	19E†	"	102077	4	478
	Log. average (21E and 22E) = 36354; s.d. of log. life = 0.032				

†Specimen GR19E was inadvertently subjected to a compressive overload of about 400 kN at 24,157 flights. It was unbroken after 102,077 flights, when it was statically loaded in tension and failed through a small fatigue crack at hole 4.

TABLE 4(a) - COLD-EXPANDED HOLES

Spectrum	Specimen no. GR	Gross area stress (MPa) at + 7.5 g*	Life (flights)	Failure hole no.	Failing Load (kN)
French	16D	294	2362	2	336
	26D	"	2818	4	340
	5D	"	2913	4	338
	8B	"	3136	4	330
	12B	"	3223	4	332
		Log. average = 2874; s.d. of log. life = 0.053			
	6D	235	14742	4	303
	19D	"	16542	4	264
	3D	"	20427	4	265
	23D	"	24413	4	271
	9D	"	25813	4	240
	11B	"	25842	2	283
	2D	"	26781	2	267
		Log. average = 21570; s.d. of log. life = 0.104			
Swiss	25D	294	1971	4	342
	10D	"	2108	2	364
	8D	"	2143	4	351
	9B	"	2505	2	322
	14D	"	2571	4	366
		Log. average = 2247; s.d. of log. life = 0.050			
	24D	235	11647	2	298
	13D	247	13048	4	Not recorded
		[Life adjusted to stress of 235‡	(19613)]		
	4D	235	18344	2	294
	6A	"	19743	2	295
	12D	"	21447	4	303
		Log. average = 17343; s.d. of log. life = 0.119			
	"Adjusted"	Log. average = 17775; s.d. of log. life = 0.105			

*Nominal machine forces at '+ 7.5 g' load were 316 kN for 7.5 g stress of 235 MPa and 395 kN for 294 MPa.

‡Using relationship given in Reference 2.

TABLE 3 - GROSS AREA STRESS VALUES FOR FRENCH SEQUENCE

'g'	stress (MPa)
+7.5	235
+6.5	204
+5	157
+4	125
+3	94
+1	31
+0.5	16
0	0
-1.5	-47
-2.5	-78

Maximum load range of sequence, +7.5 g to -2.5 g ≡ 313 MPa

Minimum load range of sequence, +3 g to +1 g ≡ 63 MPa

$$\text{Ratio} \quad \frac{\text{minimum range}}{\text{maximum range}} = 0.20$$

Specimen no.
GR 25D
Flights:
1,971

Specimen no.
GR10D
Flights:
2,108

Specimen no.
GR 8D
Flights:
2,143

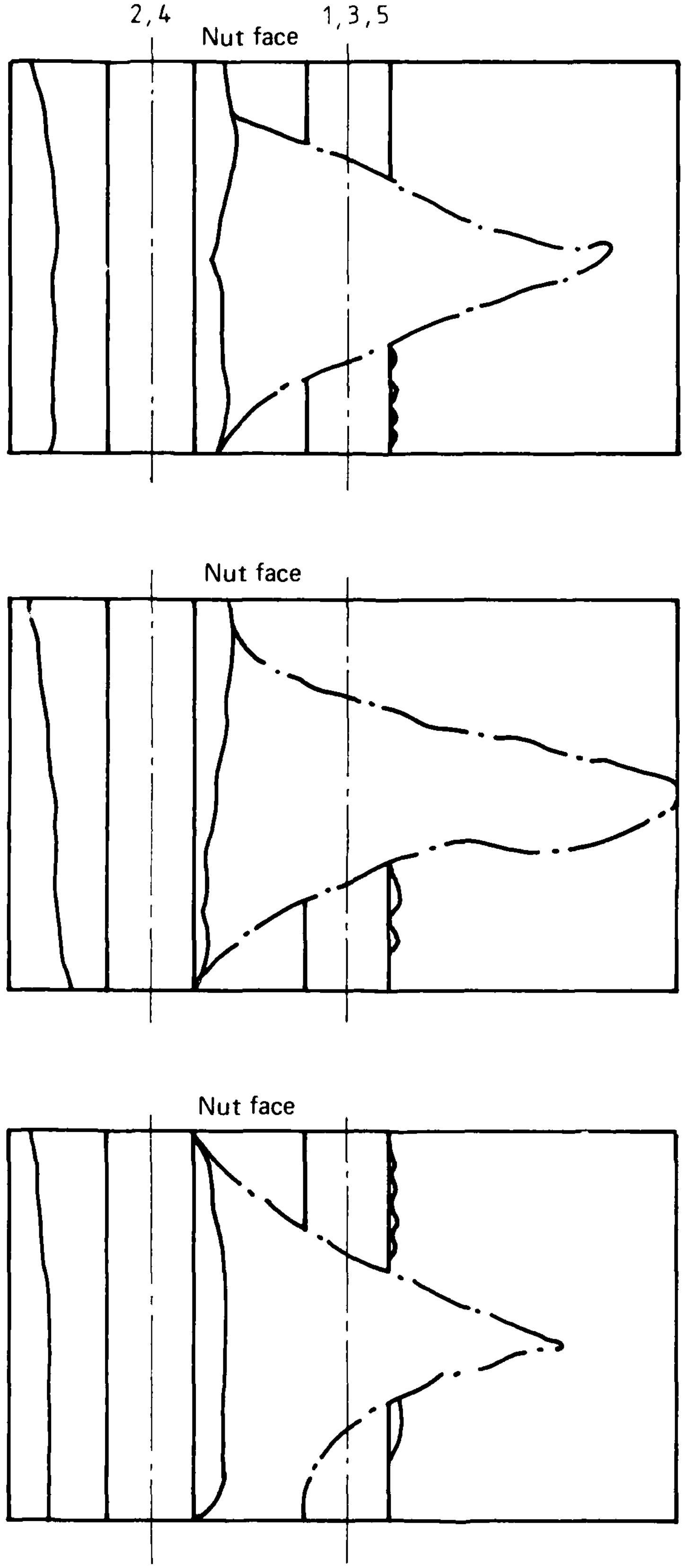
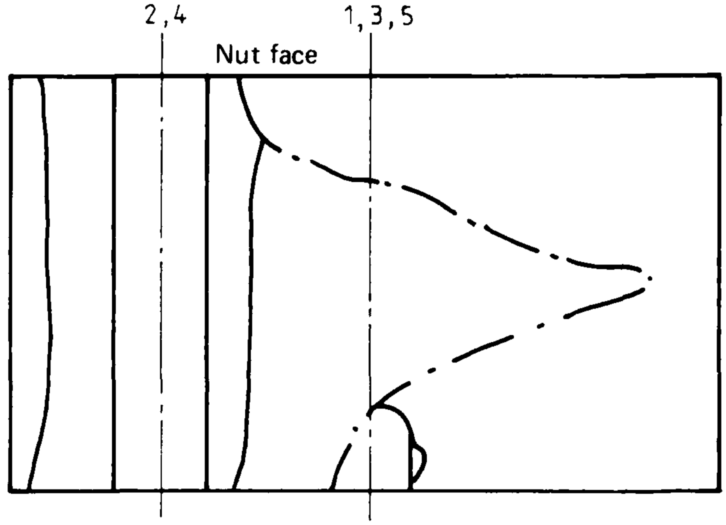


FIG. 6(b) FRACTURE SURFACES: SPECIMENS TYPE (C)
COLD – EXPANDED HOLES, SWISS SEQUENCE,
+7.5g = 294 MPa

Specimen no.
GR9B

Flights:
2,505



Specimen no.
GR14D

Flights:
2,571

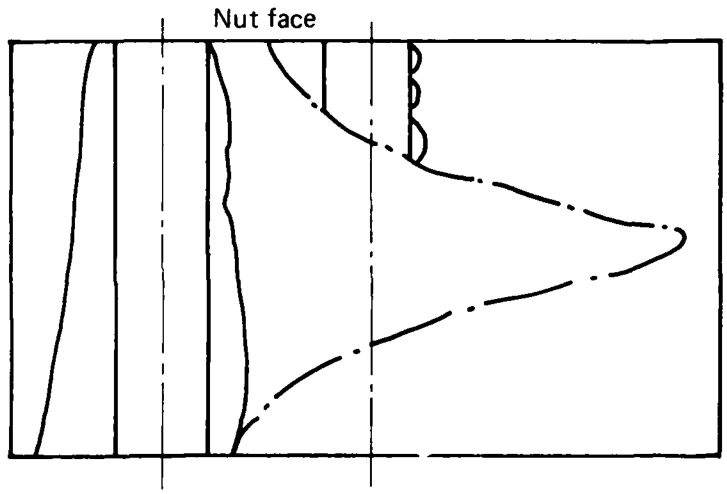


FIG. 6(b) FRACTURE SURFACES: SPECIMENS TYPE (C)
COLD – EXPANDED HOLES, SWISS SEQUENCE,
+7.5g ≡ 294 MPa

Specimen no.
GR 24D
Flights:
11,647

Specimen no.
GR13D
Flights:
13,048
(see Fig. 7(a))

Specimen no.
GR 4D
Flights:
18,344

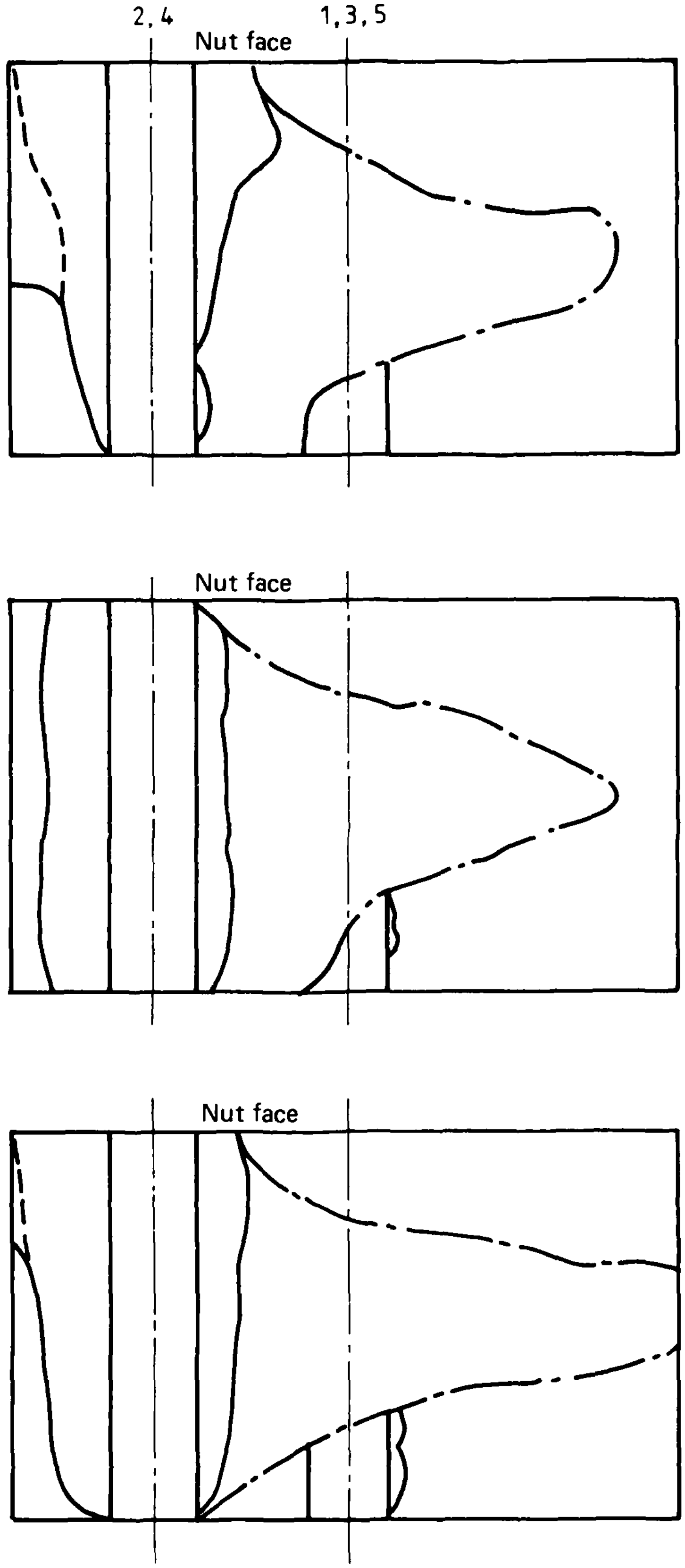
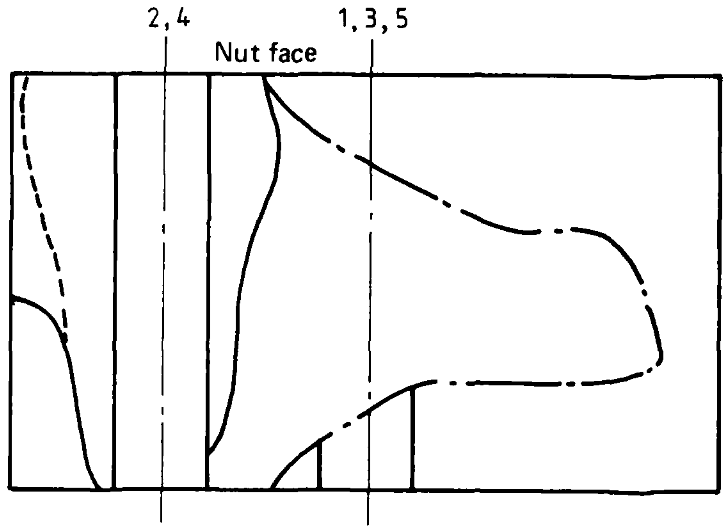


FIG. 6(b) FRACTURE SURFACES: SPECIMENS TYPE (C)
COLD – EXPANDED HOLES, SWISS SEQUENCE,
+7.5g ≡ 235 MPa

Specimen no.
GR 6A
Flights:
19,743



Specimen no.
GR12D
Flights:
21,447
(see Fig. 7(a))

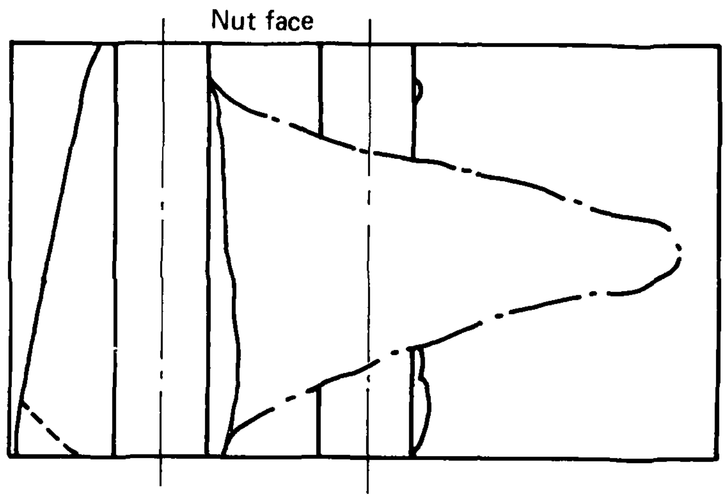


FIG. 6(b) FRACTURE SURFACES: SPECIMENS TYPE (C)
COLD -- EXPANDED HOLES, SWISS SEQUENCE,
+7.5g ≡ 235 MPa

Specimen no.
GR17E
Flights:
27,013

Specimen no.
GR20E
Flights:
30,227

Specimen no.
GR23E
Flights:
41,242

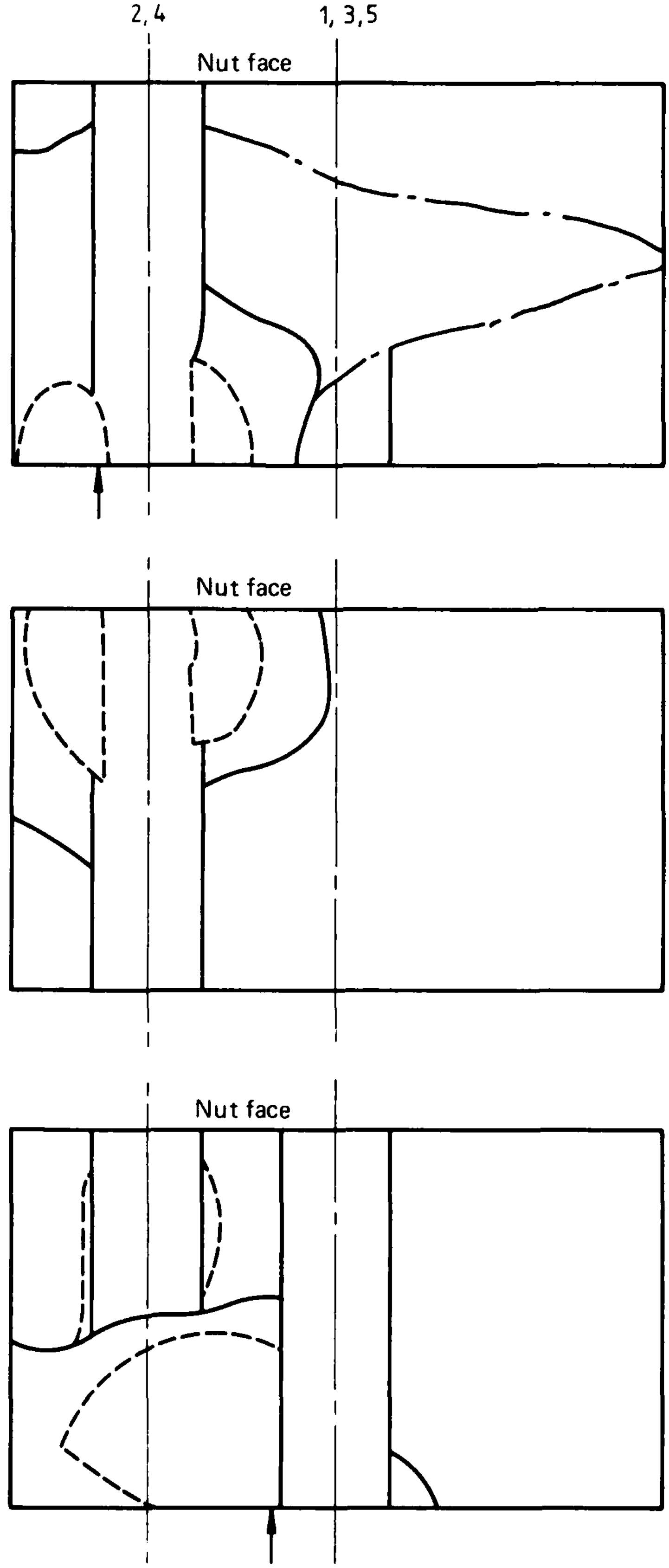
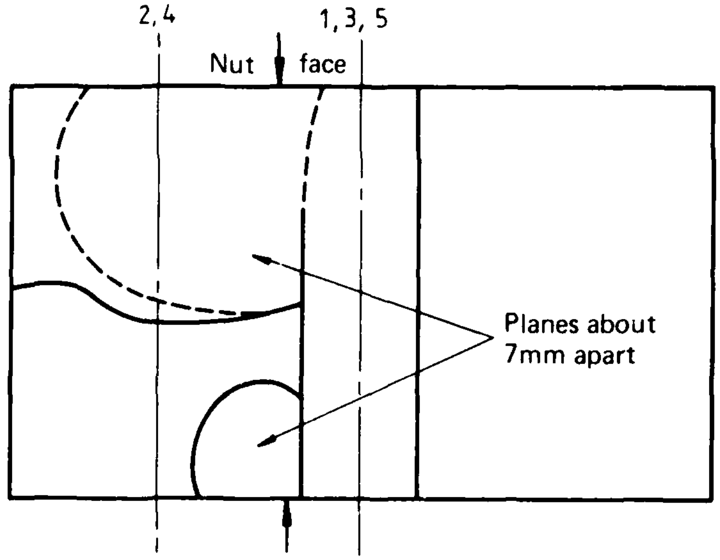


FIG. 6(c) FRACTURE SURFACES: SPECIMEN TYPE (D)
INTERFERENCE – FIT BUSHES, FRENCH SEQUENCE
+7.5g ≡ 235 MPa

Specimen no.
GR12E

Flights:
41,542
(see Fig. 7(b))



Specimen no.
GR25E

Flights:
61,342

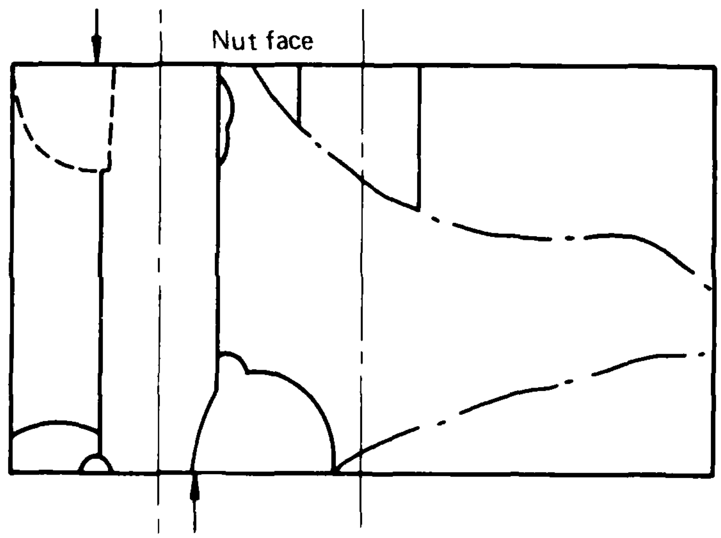
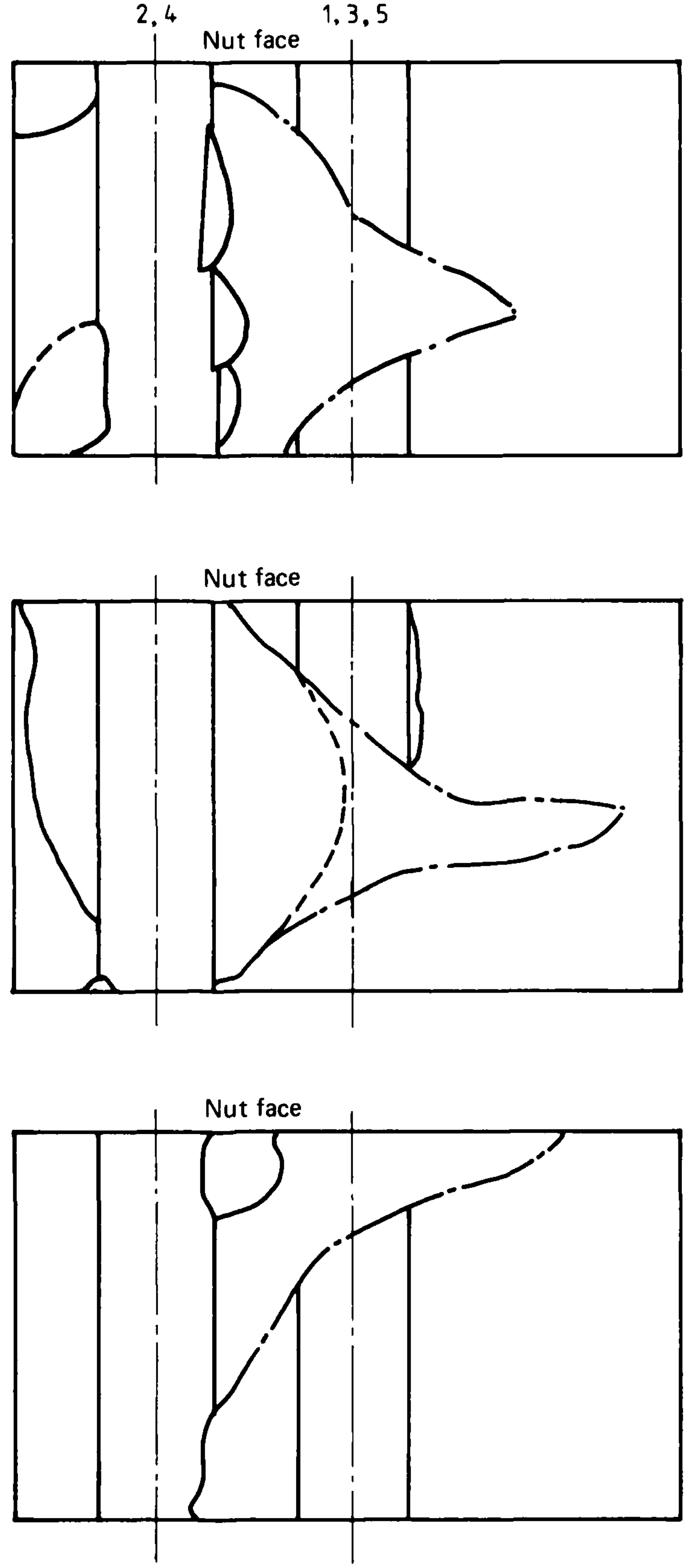


FIG. 6(c) FRACTURE SURFACES SPECIMEN TYPE (D)
INTERFERENCE FIT BUSHES FRENCH SEQUENCE,
+7.5g 235 MPa



Specimen no.
GR21E
Flights:
34,508
(see Fig. 7(b))

Specimen no.
GR22E
Flights:
38,298

Specimen no.
GR19E
Flights:
102,077

FIG. 6(d) FRACTURE SURFACES: SPECIMENS TYPE (D)
INTERFERENCE – FIT BUSHES, SWISS SEQUENCE,
+7.5g = 235 MPa

Nut face

Specimen no.
GR 12B

French sequence
+7.5g ≡ 294 MPa

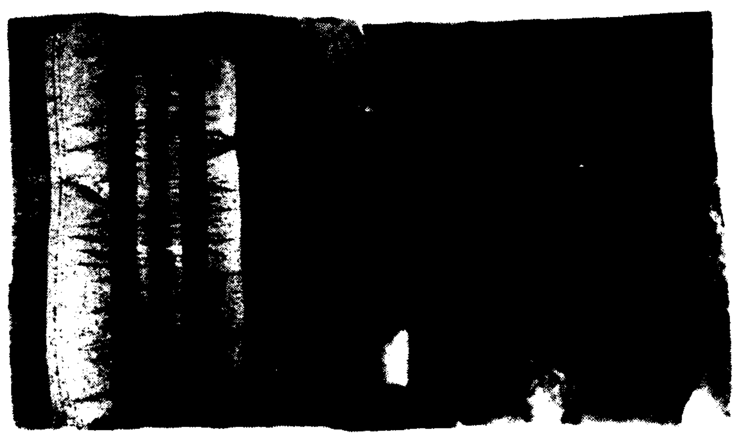
Flights:
3,223

Nut face

Specimen no.
GR 13D

Swiss sequence
+7.5g ≡ 235 MPa

Flights:
13,048



Nut face

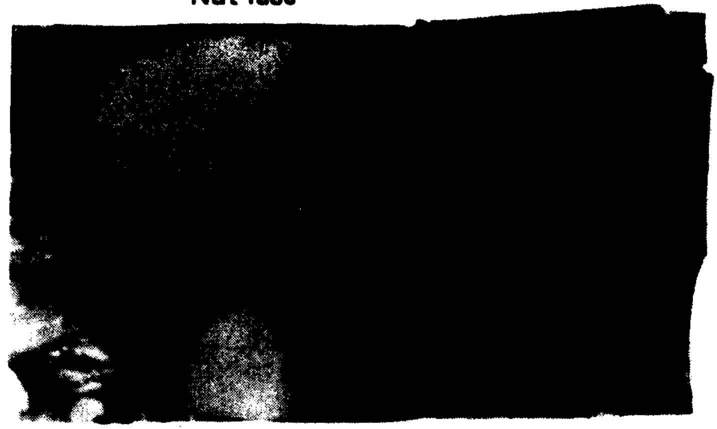
Specimen no.
GR 12D

Swiss sequence
+7.5g ≡ 235 MPa

Flights:
21,447

FIG. 7(a) FRACTURE SURFACES: SPECIMEN TYPE (C)
COLD – EXPANDED HOLES

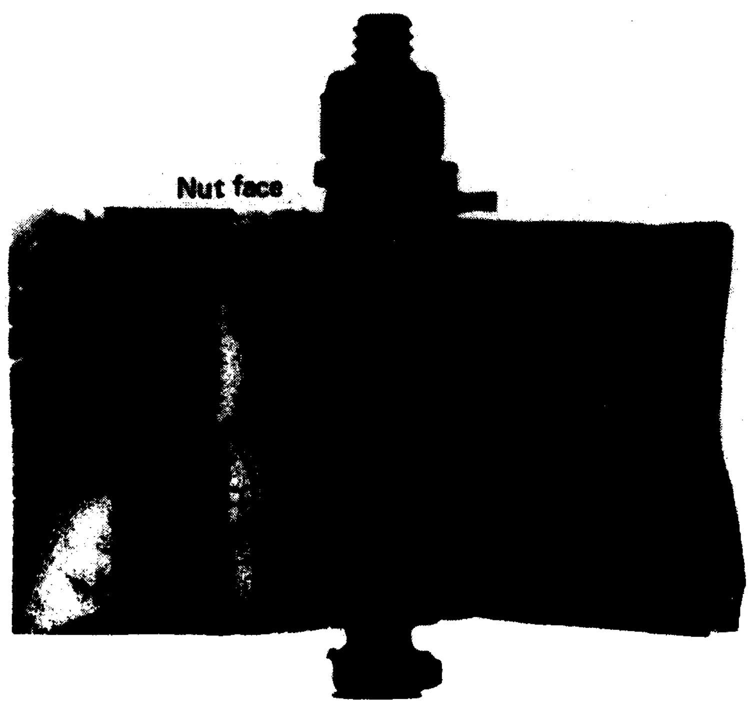
Nut face



Specimen no.
GR12E

French sequence
+7.5g ≡ 235MPa

Flights:
41,542



Specimen no.
GR 21E

Swiss sequence
+7.5g ≡ 235 MPa

Flights:
34,508

FIG. 7(b) FRACTURE SURFACES: SPECIMEN TYPE (D)
INTERFERENCE – FIT BUSHES

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Cold working		
Fasteners (interference)		

16. Abstract

Flight-by-flight fatigue tests were carried out on specimens representing part of the front flange of the main spar of the Mirage III wing. Two loading spectra/loading sequences were used, the first being a 200-flight sequence incorporating 24 different types of flight developed by the Eidgenössisches Flugzeugwerk in Switzerland and the second a much simplified 100-flight sequence incorporating only 4 different types of flight developed by Avions Marcel Dassault in France.

The fatigue tests showed that there were no significant differences in the lives to failure between specimens tested under the two sequences, and it was therefore concluded that the use of the

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